

TURBOMACHINERY HEALTH MEASUREMENT APPLICATION AND MISAPPLICATION—PART II

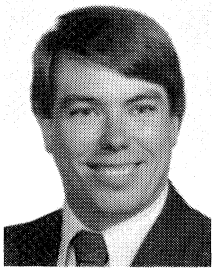
by

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ABSTRACT

In Part I of "Turbomachinery Health Measurement - Application and Misapplication" (*Proceedings of the 17th Turbomachinery Symposium*, 1988) the fundamentals of machinery monitoring were presented. This tutorial is presented with the assumption that the reader understands all the basic measurement tools and how they operate. The person who uses these tools to determine the internal state of rotating equipment must be thoroughly familiar with how these tools work individually and in concert with other tools. While the monitoring process must be customized for each class of equipment, the degree of scrutiny is often limited by available resources and the economic justifications. Computer based monitoring systems are rapidly closing the gap between permanent monitoring and routine periodic monitoring. The attempt is made to guide the user toward using his monitoring equipment and human resources to maximize effectiveness and avoid common mistakes. A discussion of the most common instrumentation usage is presented, along with the pitfalls associated with misapplications.

INTRODUCTION

Measurement of the state of health of turbomachinery can be divided into three major segments. First are permanent monitors on critical equipment. Permanent monitoring may be justified on expensive unsparred machinery based on both the cost savings in repairs and lost production. Permanent monitoring is also justified on machines that are in extreme service or require frequent or costly maintenance. Second are those machines that are monitored on a routine basis by portable gen-

eral purpose equipment. These first two areas were covered in the earlier presentation. The third area, and perhaps the most interesting to those in the engineering field, is diagnostics of specialized equipment problems. Typically, this activity is triggered by an alert from one of the first two monitoring systems. This function requires unique personnel with exceptional skills.

As interesting as they are, specialized diagnostics usually mean trouble, which often means expensive repairs and down time. Unfortunately, specialized diagnostics and unusual expense have become associated in some minds. Cut the former and reduce the other, correct? One of the reactions to this has been to make permanent monitoring systems "smarter" by interfacing them with various computer systems. Observe the permanent monitoring systems being marketed today, and indeed computer based systems are hot items. Likewise, the computer based handheld data collector market has blossomed. As if instrument capabilities alone will solve problems, a raging competition over specifications and features has developed. Many of these new features are very useful and informative. For example, a monitor measuring vibration filtered at running speed might ring a different alarm than one measuring only gear pass frequency. More complicated systems might even correlate process variables such as oil temperature or discharge pressure with vibration levels to better define acceptable operational limits. For example, a pump operating at 30 percent of design flow might have a different set of vibration alarms than when operating near design flow. The potential is almost without bounds. The question is, can this amount of data be managed and boiled down to something useful; something that will increase efficiency and reduce costs? Eventually, the answer will be yes. It will take development of very large data bases that can be statistically manipulated and analyzed by expert systems. Today, trained people must make these decisions.

Some of these new tools have become so complicated that only a fraction of their potential is used routinely. With these new systems, one can manipulate and massage a set of data, in the hopes of wringing the truth out of the raw signals, until all the cross correlations, coherences and multispeed orbits have been printed out and examined. It is the firm belief of this author that concentration on the basics of signal analysis will yield rapid accurate diagnoses of machinery problems and economically sound solutions. As one progresses toward learning the more advanced analysis techniques, the power of the newer analysis tools will become invaluable and, more importantly, truly useful.

To reiterate a sentiment from the 1988 presentation, the ultimate goal of monitoring is to determine what is going on inside a machine, without actually shutting it down and opening it up. There is no one right way to analyze the health of turbomachinery, but there are some wrong choices. There is no one right set of instrumentation for diagnostics, but such instrumentation can be misapplied or misinterpreted unless the user is fully aware of all aspects of the analysis process.

INSTRUMENTATION SYSTEMS

There is no universal instrument, because the rotating equipment systems analyzed are complicated and varied. Many instruments are committed to performing simple tasks very well. Voltmeters and oscilloscopes fall in this category. Some instruments are dedicated to performing single complicated tasks. Structural modal analyzers fall in this category. The trend today is to pack as many features into a single instrument as possible. One instrument can now serve as oscilloscope, spectrum analyzer, tracking filter, modal analyzer, and storage device. This has advantages as well as drawbacks.

INSTRUMENTATION USAGE

This section will cover most of the instruments used in diagnosing machinery health. Many of the basics were covered in the previous article and will not be repeated here. However, there are many techniques and pitfalls that are not readily apparent. Combining powerful analysis tools with innovative techniques will yield better results.

Oscilloscopes

This author always carries an oscilloscope along on a job, even though the fancy portable analyzer also along can do the same job. A dedicated analog oscilloscope can be flipped from one frequency range to another much faster than a portable analyzer. As shown in Figure 1, one can rapidly observe the fundamental part of a vibration signal, then quickly look at many vibration cycles, which in this case indicate a subsynchronous excitation. Using the digital portable analyzer, there is often the need to page through multiple menus, setting sampling rate, bandwidth, sample size and anti-alias filter. With power also comes complexity, but sometimes there is an urgent need for speed. There are situations where seconds count in an analysis: do we shut down or not? Also, if it is too difficult to do, will the analyst bother to look at the signal in several different ways? One advantage of the oscilloscope is that it has dedicated knobs to rapidly switch frequency and amplitude ranges. One advantage of the digital data collector is the ability to permanently store such data for later analysis. During a signal monitoring opera-

OSCILLOSCOPE TRACES

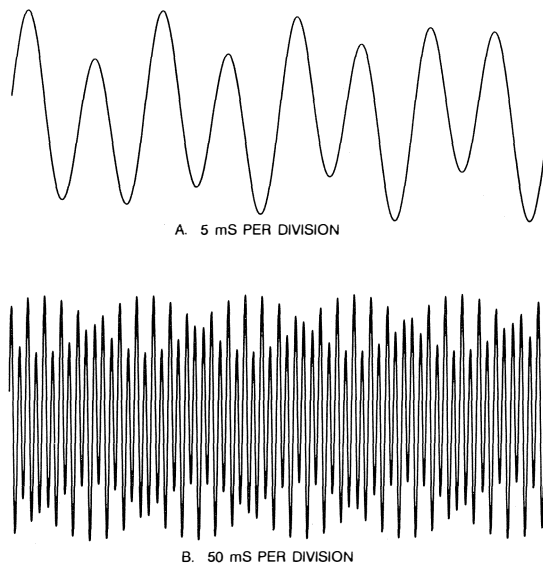


Figure 1. Frequency Ranges Reveal Subsynchronous Vibration.

tion, the oscilloscope can be left on to monitor the time base while other instrumentation performs additional diagnostics. Given a tachometer signal, the oscilloscope can be used to monitor phase through the external intensity input.

There is an extremely valuable tool, often overlooked, that displays some time base data even better than an oscilloscope. This is the strip chart recorder. In combination with a recording device (see *Data Recorders*), one can plot the signals from many channels simultaneously. A very rapid startup or run down is often difficult to analyze. Using this technique involves taping the data at a high record speed and playing back the data at a much slower speed (typically 16:1 or 32:1 speed reduction). Using appropriate signal conditioning and plotting the output on the multi-channel strip chart recorder gives tremendous insight. The rundown of a motor driving a large centrifugal pump is shown in Figure 2. Note that the large synchronous vibration component subsides almost immediately when power is removed. Notice that a significant DC shift of the proximity probe gap is also seen indicating a sudden eccentricity change. From this strip chart data of two orthogonal probes, the running speed orbit, its location, and the rundown shift of shaft centerline were manually plotted in Figure 3. These plots correctly predicted a nonconcentric air gap on the motor and initiated a shutdown and repair that prevented serious damage to the machine. The strip chart recorder is a natural for extremely low speed machinery such as rotary kilns and mixers. As long as the transducer can respond, the strip chart output can be analyzed visually. The motion shown in Figure 4 is of a variable speed rotary kiln, as it encounters a system resonance. With this speed range electronically bypassed, the problem was cured.

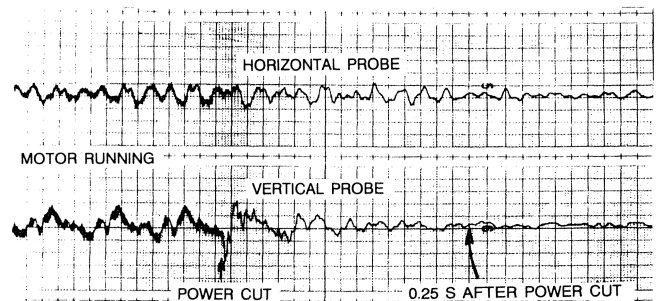


Figure 2. Strip Chart Reveals Electrical Motor Fault.

Data Recorders

The principal instrument used for data recording is the frequency modulation (FM) tape recorder. This instrument has a frequency response extending from zero Hz (DC voltage) to above 20,000 Hz depending on design and tape speed. Amplitude modulation (AM) recording is also available for higher frequencies but low frequency response is limited to approximately 20 Hz. The zero frequency capability is necessary to gather probe gap data. One of the problems associated with collecting DC voltage data along with the dynamic data is the DC voltage shift that occurs as a journal rises on the oil film during startup (or settles during rundown). The amplitude range of the recorder must accommodate this DC shift and still maintain adequate sensitivity to the dynamic data. If the DC gap voltage is not required, the signal may be AC coupled with a series capacitor. Until recently, most data tape recorders with eight channels or more were bulky reel-to-reel type. Today, VHS cassette and digital audio tape (DAT) units are available with excellent response characteristics and are more portable.

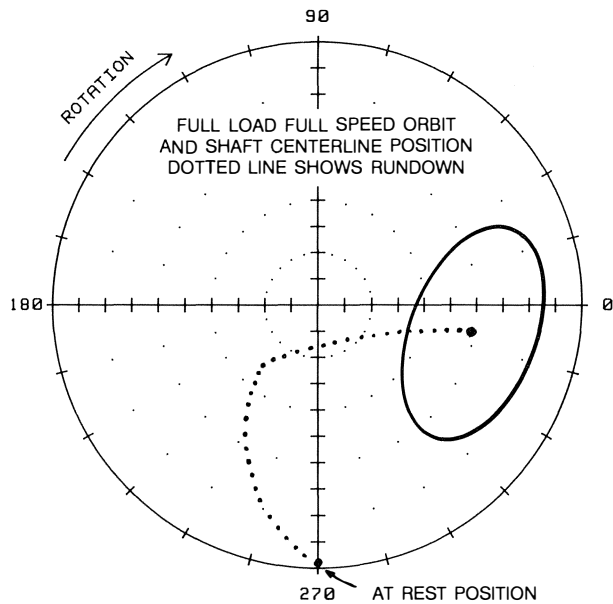


Figure 3. Shaft Centerline Plot from Strip Chart.

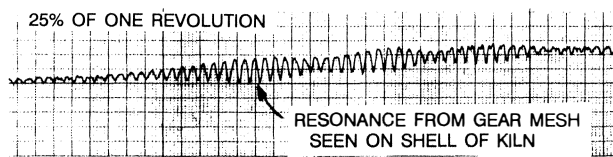


Figure 4. Strip Chart Shows System Resonance.

FM Tape recorders have frequency response ranges that are speed dependent. For example, at 15 inches-per-second (ips) tape speed, a typical unit's frequency response might be 0 to 5,000 Hz. At 7.5 ips the response would be 0 to 2,500 Hz, and so forth. This property can be used advantageously as a low pass filter eliminating high frequency noise. A scratch on a shaft will be "seen" by a proximity probe as a displacement and the spectrum will show a lot of erroneous high frequency content. Recording at a slower speed will sometimes mask the scratch, as shown in Figure 5.

It is very important to use only the very best quality tape, and many people will only use a tape only once, although this author has reused tape successfully on several occasions. Tape heads and guide paths must be cleaned and demagnetized regularly. It is recommended that this be done before each use or after every two tapes. Tapes must be stored at moderate temperatures and humidity. The tape manufacturer can supply the details of storage requirements. Finally, being a mechanical device, a yearly factory calibration of each tape recorder is highly recommended.

One problem, print through, is the carry over of magnetic signal from one piece of a recording to the adjacent piece of tape. This can become noticeable after approximately two years of storage. Thicker (i. e., shorter) tapes and some of the newer tape formats are less prone to print through than the older reel-to-reel or audio cassette tapes.

To ensure maximum playback accuracy, a calibration signal should be included at the beginning of each tape on all channels. Playback on the same piece of equipment as that which made the recording is the only way to achieve the best amplitude and phase accuracy. A set of setup data sheets for each recording must be made identifying the signals going into each channel

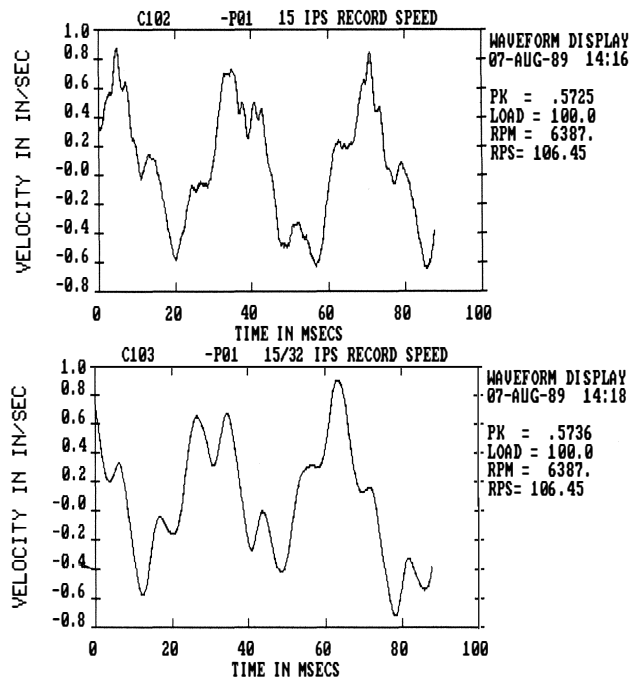


Figure 5. Slow Speed Recording Filters Input Data.

and the channel sensitivity. A second sheet, the running event sheet, must be kept to keep track of events during the recording such as load changes. Many recorders have a voice track to record event data. This author always gets so absorbed in what is happening, he often finds it easier to jot down a memo on the log sheet, rather than to record his observations on the voice track!

Another way of achieving data recording is the use of solid state memory to store the data. This works very well, especially for transient data. The limitations include losing data if all power is lost, and dynamic range is sacrificed to achieve longer "recording" times. Memory, however, can be erased in a flash and used over and over again.

One final caution about data recorders. Strange things have been known to happen to tapes between the recording and the data reduction. Stray magnetic fields are all around us. When taping a runup/rundown that is particularly important, make a live plot with a tracking filter and pen plotter. If nothing else, this will be proof that the data reproduced later is accurate.

Tracking Filters

The tracking filter is a very powerful diagnostic tool. The most common usage is startup and coast down tracking of synchronous vibration and phase. This is referred to as transient vibration tracking. A typical rundown of a compressor in Bodé form is shown in Figure 6 and the same data is depicted in polar form in Figure 7. Transient vibration data can be gathered from non-contacting displacement probes or seismic pickups such as velocity coils or accelerometers.

The main requirement for a tracking filter is a good once-per-turn trigger signal. Multiple pulses per revolution will be discussed later. This trigger is usually generated by a proximity probe sensing a hole (or projection) in the rotating element, or an optical pickup sensing a reflective piece of tape attached to the shaft. A strong word of caution is necessary here about how a particular instrument triggers. The user must understand the logic of the instrument and the sensing method. For example, one popular tracking filter triggers on the leading edge of a notch

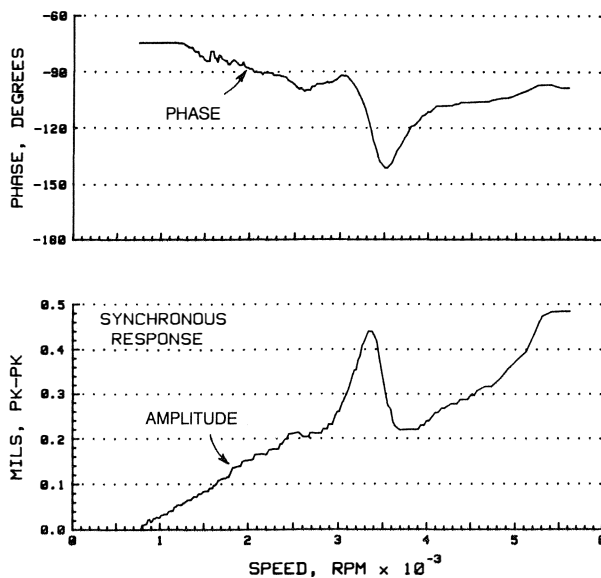


Figure 6. Amplitude and Phase Vs Speed (Bode) Plot.

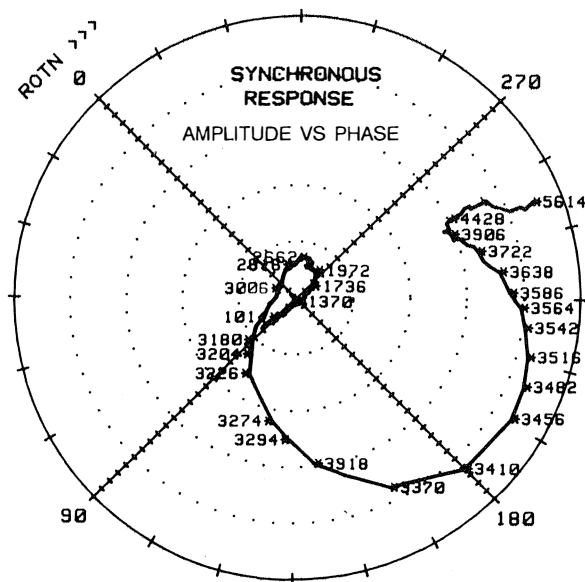


Figure 7. Amplitude Vs Phase Angle (Polar) Plot.

sensed by a proximity probe, but triggers on the trailing edge of an optical tape input. This triggering logic is vital to accurate phase measurement, particularly when balancing rotating equipment in place.

Many machines are either without a phase reference transducer entirely, or it is inoperable. If a quick shutdown is possible, it is easy to add a temporary optical trigger. Many times shutdown is not possible. There are several unconventional methods that sometimes will yield an acceptable trigger signal. The first is to sense a key or keyway with a proximity probe. Setting this probe while the machine is running is dangerous. Proceed with extreme caution and use a strobe light if possible. Occasionally, a governor tachometer signal can be used. If the machine is equipped with proximity probes, a scratch or dent in the shaft can be amplified and used with appropriate signal conditioning. This technique is illustrated in Figure 8. If the

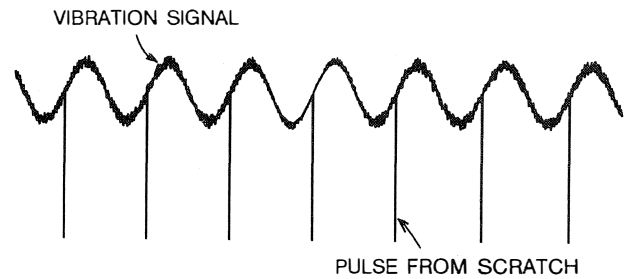


Figure 8. Use of a Scratch in Vibration Signal for Trigger.

machine is equipped with axial position probes, there is often enough axial runout to serve as a trigger source, although this will yield less accurate phase data than a single pulse.

The synchronous tracking of amplitude and phase vs speed yields much useful diagnostic data. Critical speeds are located, and the startup and shutdown procedures can be tailored from this information. Structural resonances can be identified, particularly when seismic transducers are used in conjunction with proximity probes. One useful calculation is that of the rotor amplification factor. This is done from a synchronous runup or rundown Bode plot. Rundown plots are generally preferred after the machine has reached operating conditions and stabilized. For example, it is not unusual to observe proximity probe vibration signals of a steam turbine change phase angle 60 to 90 degrees as the rotor heats up. The amplification factor can be calculated several ways, but the most popular is the half power point method illustrated in Figure 9, as defined by API specifications. However, this calculation must be made very carefully. First, if proximity probe data is used, it must be vectorially runout subtracted data. In reality, if significant, the motion of the probe itself should also be vectorially subtracted before the final calculation. Note that vectorially subtracted runout may well add to the vibration signal. Using raw data can yield erroneous results (Figure 10). For diagnostic purposes, the transition through the first critical speed should neither be very rapid nor very slow. A very rapid run through the first critical speed will be difficult for the tracking instrument to follow. Zero to 10,000 rpm in three seconds is probably beyond the ability of most tracking filters. Likewise, if a rotor is allowed to "hang" in the critical speed zone too long, amplitudes can build to the point of becoming nonlinear.

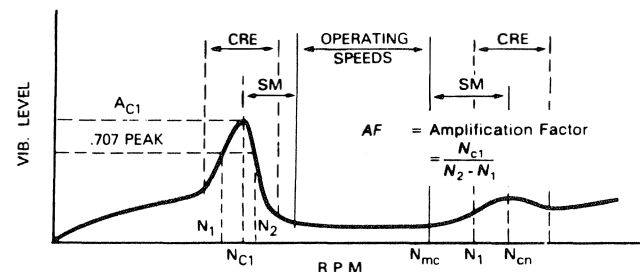


Figure 9. Amplification Factor by the Half Power Point Method.

There are other methods of synchronous order tracking that can yield insight into machinery health condition. Much has been written about tracking twice running speed vibration for detecting cracked shafts. However, this is a much too complicated subject for this tutorial.

One technique this author has developed is using higher multiple events per turn as a trigger source, such as gear pass frequency, to identify casing resonances and even shaft critical

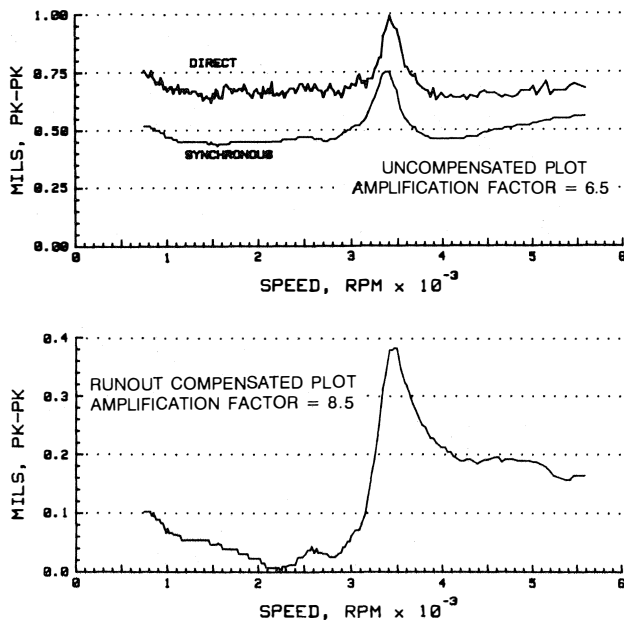


Figure 10. Uncompensated Signal Yields Erroneous Results.

speeds above running speed. The casing vibration shown in Figure 11 is from an accelerometer during the runup of a gearbox. Gear pass monitored with a proximity probe was used as the trigger. Modal testing confirmed that several peaks were gearbox casing resonances and that one peak was most likely the pinion's predicted first critical speed.

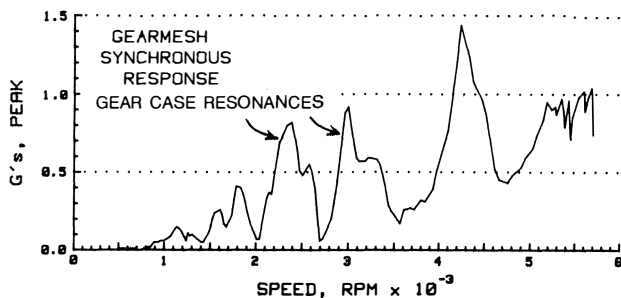


Figure 11. Seismic Transducer Reveals Casing Resonance.

Spectrum Analyzers

No diagnostic tool is as ubiquitous today as the fast Fourier transform (FFT) spectrum analyzer. In reality, the main function of such a device is to capture, store and display the frequency domain transform of time base data. What true analysis is done is performed by the user of this powerful tool. There are many other capabilities inherent in the FFT which enhance its utility and also complicate its usage. This tutorial will not make the reader an expert at using spectrum analysis. Only devoting many hours with an instrument and examining many types of signals will bring this understanding. To the beginner, this author strongly recommends setting up the FFT instrument with a signal generator and trying various combinations of input and display options. Do not begin by trying to analyze the most complicated vibration problem in the plant! The majority of spectrum analysis is done to individual signals one at a time. Single channel FFT instruments allow input of one time wave and usually a synchronous tachometer pulse. The user must decide how to

set up the instrument. First, a frequency range must be selected. The natural tendency is to select a range that covers not only running speed but any other higher order frequencies that may be expected. Sometimes a single frequency range is not enough. For example, consider a 1,750 rpm motor driving a 6,780 rpm compressor through a speed increaser. A spectrum from the gear box showing both running speed and gear mesh (rpm times number of gear teeth) frequencies is shown in Figure 12. Often, a second spectrum (Figure 13) is really necessary to show the running speed vibration levels clearly. A third spectrum (Figure 14) may also be necessary to investigate the gear mesh frequency components and side bands. Gear mesh side bands are very important in diagnosing gear condition.

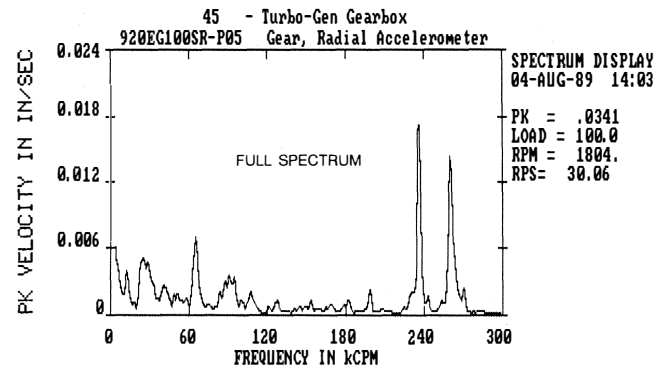


Figure 12. Full Spectrum from Gearbox.

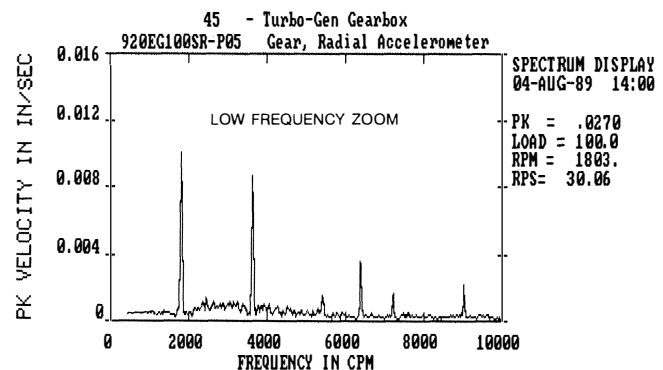


Figure 13. Running Speed Components Revealed by Selective Zoom.

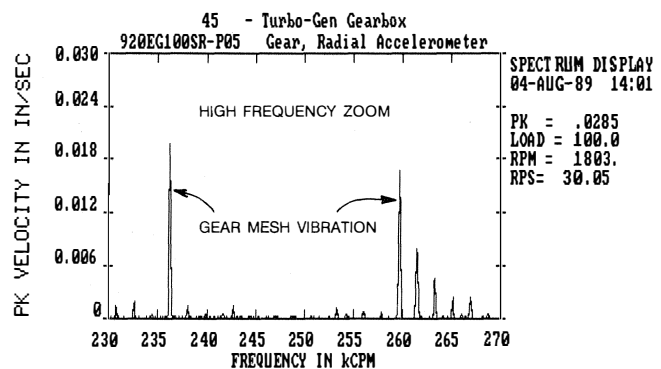


Figure 14. Gear Mesh Frequencies Revealed by Selective Zoom.

Frequency accuracy is important to the analyst. This depends on the resolution of the instrument at the settings chosen. For example, the most commonly touted FFT attribute is the number of available lines. This is simply the number of discrete digital filters in the analysis span. If the total span is 1,000 Hz and the resolution is 100 lines, the filter spacing is 10 Hz. Attempting to use this setup to read resolutions of one Hz will not yield meaningful results. On the other hand, using extremely high resolution, such as 3,200 line resolution, will not yield much in general use, except frustration waiting for the analysis to complete. The finer the resolution, the longer it takes to sample and calculate the FFT. These are laws of physics; only the computation time can be shortened. It can be argued that, instead of three spectrums to examine, the entire range and specialized segments of the spectral band, rather a very fine resolution scan will accomplish the same results. This is true, but "zooming" into these narrow bands is still necessary for proper resolution and will often take just as long as making separate spectrums. This author recommends 400 line resolution for all general purpose data collection and analysis. One example (Figure 15) where finer resolution is needed is the case of separating running speed of 3,570 rpm from 3,600 cpm electrical pulsations on an electric motor. To really see what is going on, a "zoom" analysis is called for. All this means is concentrating many lines of resolution into a narrow band. For example, if one wished to examine the electric motor mentioned previously, one could specify a span ranging from 59 Hz to 61 Hz with a resolution of 200 lines. As shown in Figure 16, frequencies could then be read from the spectrum with an accuracy of 0.01 Hz. Naturally, this could also be accomplished with a 0 to 4,000 Hz span with a resolution of 40,000 lines!

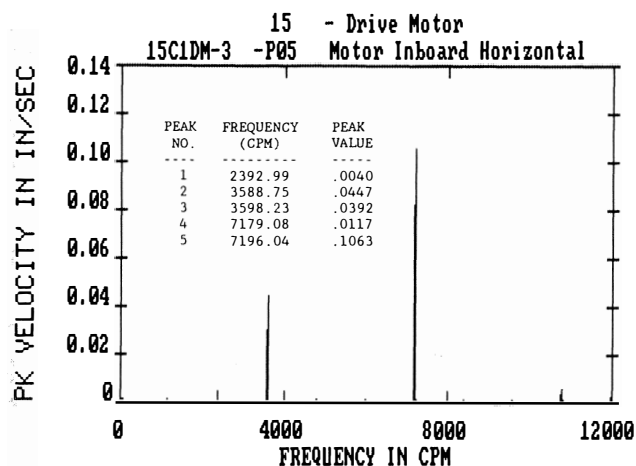


Figure 15. High Resolution Separates Electrical Vibration.

Amplitude accuracy is not obvious with FFT instruments. If the frequency being measured happens to fall exactly on the center of a discrete filter, accuracy will be optimized. If it falls between two filters, amplitude accuracy will be reduced. The degree of accuracy depends on the design of the instrument and the number of lines of resolution. Two spectra shown in Figure 17 are from one volt root mean square (rms) pure sine wave inputs to an analyzer. Note that the one at 100.0 Hz registers as 0.980 volts rms while the one at 139.9 Hz registers 0.942 volts rms. There will always be some amount of amplitude attenuation in every FFT instrument.

Another useful feature incorporated into most FFT analyzers is the user selected averaging mode. In general, to reduce ran-

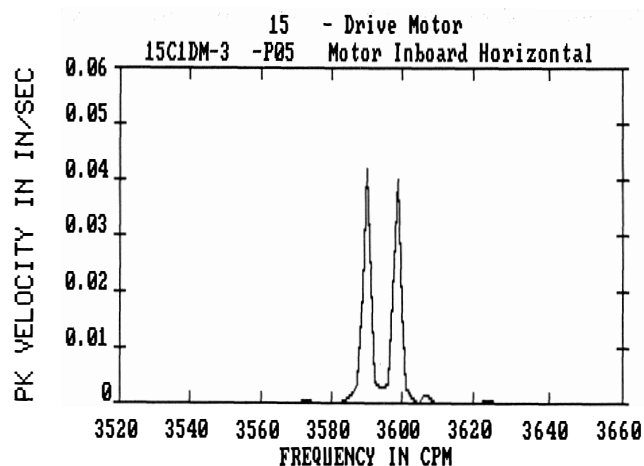


Figure 16. Zoom Analysis Shows Mechanical-Electrical Vibration.

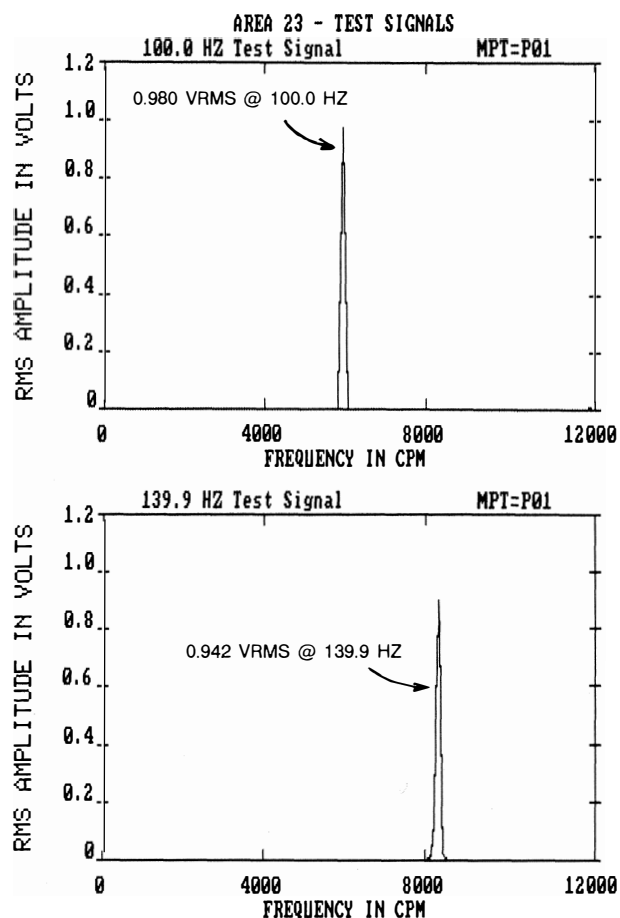


Figure 17. FFT Amplitude Accuracy Comparison.

dom background noise, rms averaging is used. Time based or synchronous averaging can be used to exclude all but multiples of running speed (or any other trigger frequency). Time averaging is useful in a multiple speed machine such as a gearbox to delineate the effects of each rotor.

An instantaneous spectrum is shown in Figure 18 with no averaging compared to the same signal with 4.0 rms averages. The

reduction of random noise is readily apparent. As background noise increases, more averages are necessary to produce accurate spectrums. For routine analysis, four to 16 averages are recommended to attain good results.

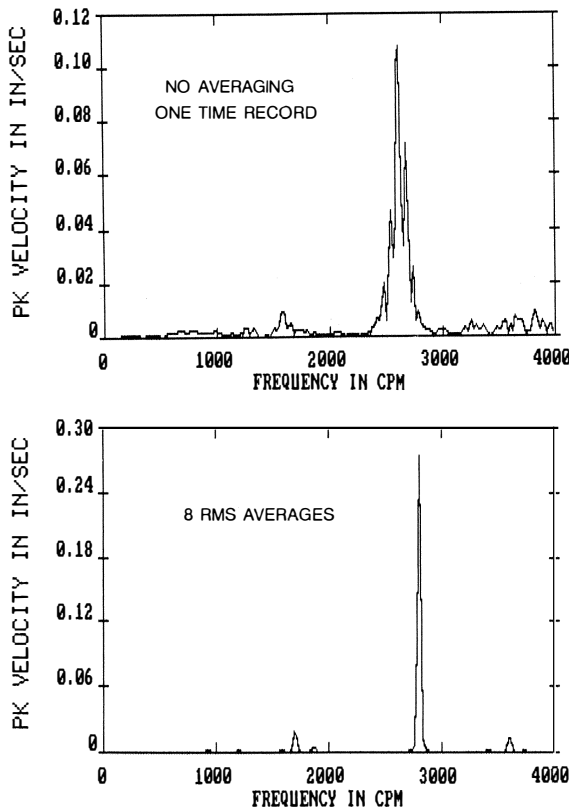


Figure 18. RMS Averaging Reduces Random Noise.

Another very useful type of “averaging” is the peak hold mode. As the name implies, this operation instructs the FFT instrument to capture the maximum amplitude that each individual filter detects and hold it until a higher level signal occurs at that specific frequency. As shown in Figure 19, during a rundown this can yield results similar to the Bode plot from a tracking fil-

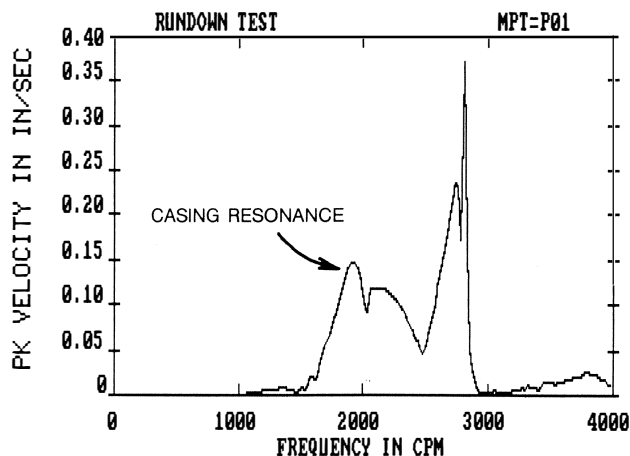


Figure 19. Rundown Captured with Peak Hold Averaging Mode.

ter. One problem with this method is that other frequencies, $2\times$, $5\times$, etc., can add to and distort the peak hold spectrum. Peak hold is also useful for capturing transient vibrations.

Peak hold can also be used as a poor man's modal test device. This is not to be confused with true modal testing, about which books have been written. This technique involves placing one or more seismic transducers on a structure and then impacting the structure with a rap, typically from a hammer. For general rotating equipment, this author has had the best results with plastic tipped hammers; the bigger the structure, the bigger the hammer. The running speed spectrum of a 3,570 rpm blower is shown in Figure 20. The principal vibration was at 50 percent of running speed. Instead of tearing the machine apart looking for looseness or rubs, a simple rap test was made as shown in Figure 21. The foundation was resonant at 1,800 cpm. The simple solution was to fill the base with epoxy grout which resulted in an order of magnitude reduction in vibration (Figure 22); nothing else was done to the equipment.

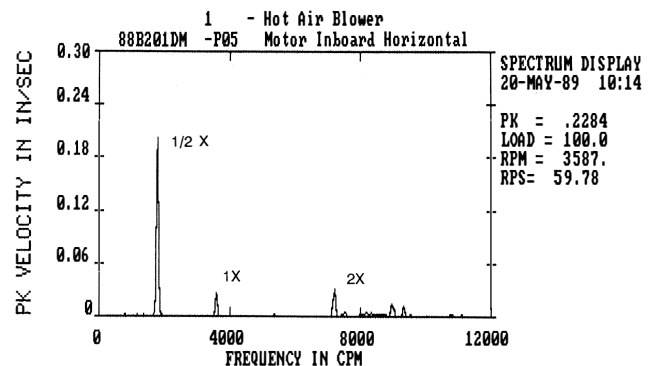


Figure 20. Vibration Spectrum of 3570 RPM Blower Running.

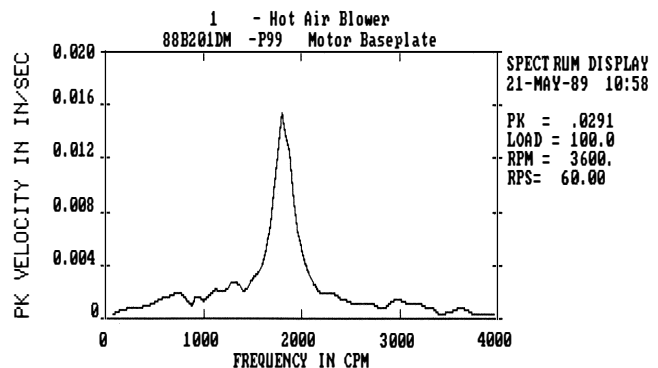


Figure 21. RAP Test on 3570 RPM Blower Not Running.

The final aspect of FFT instruments that must be discussed is that of windowing. Incoming signals are analyzed in discrete segments. The FFT algorithm assumes that this segment of data repeats itself forever. Consider a sine wave. If the sine wave just fits in an exact number of cycles per sample, the FFT transform will be accurate. However, this is almost never true. To account for this, all FFT instruments use a technique called windowing. Simply put, the data in each sample is zeroed at the beginning and end of each sample, with 100 percent of the sample at the center of the sample window. The shape of the window is determined by the type of data expected for analysis. The three most common window types are shown in Figure 23. The Hanning window is the best general window for use in collecting periodic data from the majority of rotating equipment. If in doubt, use

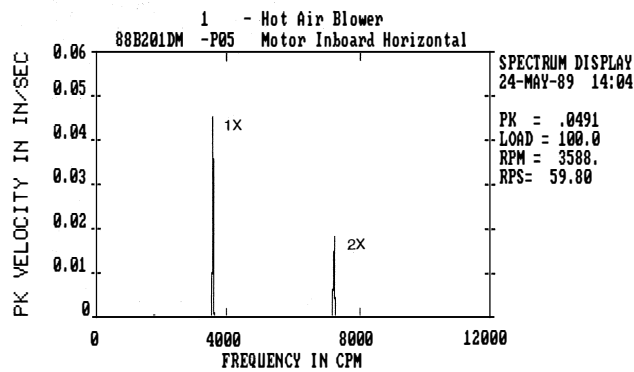


Figure 22. Vibration Spectrum of 3570 RPM Blower After Fix.

the Hanning window. The flat top window is best used for pure sinusoidal signals. The uniform window is best for capturing transient data and for rap testing. Other window designs exist for unique situations but are too specialized for this discussion.

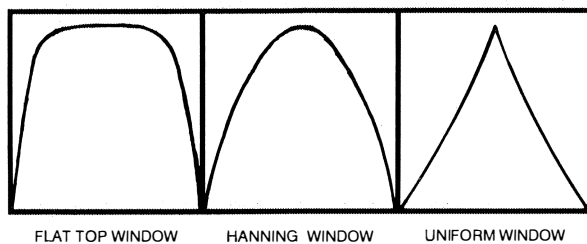


Figure 23. Spectrum Analyzer Window Types.

Multichannel FFT instruments allow much more complex signal analysis to be performed. One of the most powerful types of analysis is true modal testing. The machine to be tested is excited with a shaker or instrumented hammer. This input force is fed into one channel of the FFT instrument. The machine's response is measured and is fed into the second channel. The instrument then performs mathematical calculations to determine the spectral response from a known input. This is known as the transfer function. From these same inputs, additional calculations will yield the coherence function which is an extremely useful measure of the correctness of a particular measurement. Naturally, multichannel FFT instruments can display multiple spectrums and waveforms simultaneously as well as perform arithmetic operations between signals. Many of these capabilities are specialized and are not, nor should they be, routinely used.

TORSIONAL VIBRATION MEASUREMENT

Torsional vibrations are difficult to measure directly. This tutorial will only cover the highlights of torsional measurement. Often the indirect effects of torsional resonances are more easily detected. The Bodé plot shown in Figure 24 is of the runup of a gear pinion driven by a synchronous motor. The pronounced peak at 4,750 rpm is caused by a torsional resonance, manifested in the radial direction. The lateral motion of shafting in response to torsional excitation is a major source of torsional damping.

To measure torsional vibrations, first consider what torsional vibration means to the shaft motion. In the steady state case, as in a gas engine for example, the shaft runs at a given speed, say 600 rpm. Suppose a torsional resonance exists at 1,200 cpm and that this is a two cylinder engine. There will be an oscillatory

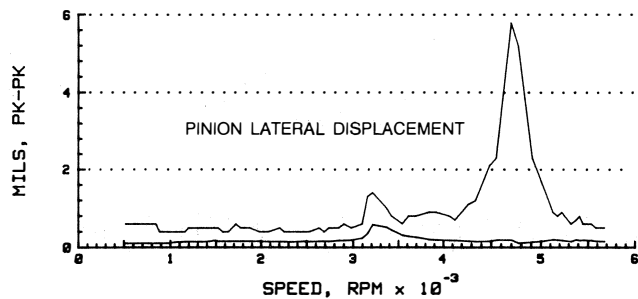


Figure 24. Torsional Resonance in Lateral Pinion Vibration.

torque superimposed on the 600 cpm running speed causing unsteady rotational motion. How can an instrument detect this? The most common way is through frequency demodulation techniques. The running speed is assumed to be the carrier frequency. When demodulated (i. e., the carrier frequency is zeroed out) any other frequencies will clearly show. Unfortunately, the torsional amplitudes are often so low that this is a difficult task. In the steady state situation, this is regularly done with great success. The really difficult problem is measuring torsional vibrations in a transient environment, particularly the startup of synchronous motors. First, the startups tend to be rapid, and there is no single steady state carrier wave to demodulate. Traditionally, one of the best ways to monitor this situation is to instrument the shafting with strain gages and slip rings and/or radio telemetry. This has the advantage of reading shaft stress levels directly. Two tangential accelerometers (to cancel out radial effects) have also been applied to shafting to measure torsional oscillations. Again, the signal must be removed via slip rings or telemetry. Plots can be made from these measurements of steady state torque, oscillatory torque, or the total torque. Other techniques involve sensing the tips of gear teeth, wrapping the shaft with chain or stripped tape to be sensed with a probe. The gear (or link) pass frequency is a very high multiple of running speed and is easier to demodulate than running speed alone. The instrumentation for accomplishing this is very specialized. One technique that this author has used is an optical encoder attached axially to a shaft end. Since very little torque is involved, a general purpose adhesive can be used to couple the two. Optical encoders typically give 120 to 1,000 pulses per revolution very accurately. Playing back the encoder's pulses from a tape recorder onto a strip chart will often yield a visual representation of the torsional vibration. An example of this is seen in Figure 25, a large multispeed gear reduction set. The major drawback to this method is that it is limited to the availability of shaft ends. Some permanent "online" torsional methods have been devised and applied to coupling spacers but all suffer from the harsh environment and maintenance they must endure.

BEARING TEMPERATURE MONITORING

Next to machinery vibration, temperature monitoring is most often used for alarms and diagnostics. Motor windings, process streams and bearings are all candidates for temperature monitoring. Sensors include local thermometers, thermocouples of various types and resistance temperature devices (RTDs). This discussion will be limited to measuring bearing temperatures.

The ultimate goal of bearing temperature monitoring is to sense what temperatures are occurring between the bearing and shaft at the minimum oil film thickness location. This is where large shear forces cause the greatest temperature increases. The easiest measure is to sense the inlet and outlet oil supply temperatures. This is useful, but limited, since it is far removed from

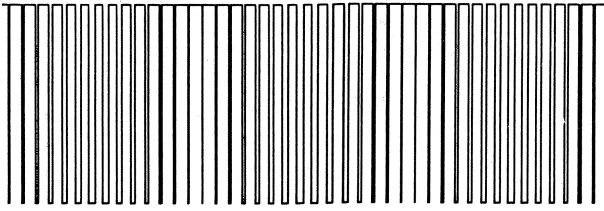


Figure 25. Visual Representation of Torsional Pulses.

the point of maximum interest and is dependent on the ratio of oil flow to heat generated. Next, there is the placement of a retractable temperature sensor into the backing shell of the bearing. This is much closer to the action and responds faster to changes than does the drain oil temperature. The best temperature sensor placement is imbedded in the bearing pads themselves, close to, but not into the babbitt layer. Experience has shown that when a hole is drilled through the steel backing and a sensor is placed in the babbitt itself, a dimple in the babbitt will almost always result. API 670 now has a very good set of guidelines for the placement and usage of temperature sensors in bearings. This guide is highly recommended.

CONCLUSIONS

So, what do you do with all this data? It turns out that, once a data acquisition system is implemented, the most difficult part begins. First, each measurement point must be set up on the database, modified when necessary, and great volumes of data must be preserved on magnetic media. The first tendency is to produce hard copy of all data collected. This will not solve any problems other than the cash flow of the local paper dealer. It is easy to be overwhelmed by the sheer quantity of data available.

A multilayered screening process is needed. Routine data is collected and automatically compared against a set of preset alarms that very conservatively will flag even the least suspect data. These alarms are not the same as those the operations personnel use. A trained technician should review all points in alarm. For example, depending on the situation, alarms might

be 0.35 ips on a pump, 1.6 mils on a compressor, or 200°F on a motor winding. This person should report anything they consider unusual to engineering. At this point a decision is made. Shut the unit down, get ready for shutdown, monitor again soon, take additional data, or pass the unit as acceptable. This process is highly dependent upon the training and expertise of those who record and those who review the data.

Ultimately, the results of years of data analysis and field repairs should coalesce into a plan that involves maintenance, engineering, and finally purchase specifications. This means that maintenance planning is optimized to efficiently renew worn out parts before catastrophic wrecks or other expensive damage occur. With the experience that comes from correlating health monitoring with actual machine condition, engineering design changes can be made to improve reliability and safety and reduce costs. There are thousands of different tasks that machinery perform in plants everyday. Some machines are better suited to these tasks than others. With a good health monitoring program, the project engineer has some ammunition to say: "No, we're not going to buy that (piece of equipment), because we have found it doesn't work well in this service. Here is the data to back this up." Or, to be more positive: "Let's purchase (piece of equipment), because we can show that it has performed well in this service in the past." To quote Charlie Jackson, a noted turbomachinery consultant, "If you don't want to have equipment problems, don't install them."

Someday there will be super computer systems that will assimilate all the turbomachinery health monitoring data. Expert systems will cross evaluate all the factors and make recommendations about how to operate and maintain equipment. There are some rudimentary forms of such systems available today. Soon, statistical evaluations of vibration data will help pinpoint operational and maintenance changes both good and bad. In the meantime, it is necessary to implement the best monitoring programs that are possible today. Educate the best people to evaluate the data and decide on maintenance techniques and design changes. Make your health monitoring system into a force that drives you to purchase better equipment and write better specifications, maintain that equipment better, increase safety, and increase your competitive edge.

